

MINING AND TRANSPORTING COAL UNDERGROUND BY HYDRAULIC METHODS: A LITERATURE SURVEY

BY WILLIAM T. BOYD

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MINING AND TRANSPORTING COAL BY UNDERGROUND HYDRAULIC METHODS: A LITERATURE SURVEY^{1/}

by

William T. Boyd^{2/}

INTRODUCTION AND SUMMARY

Foreign mining publications describing successful hydraulic mining installations, and successful domestic hydraulic mining in a gilsonite bed, have prompted the Federal Bureau of Mines to conduct a literature survey of foreign publications to determine if the hydraulic mining method can be applied to domestic coal mining. Most foreign publications do not give detailed data about the water pressures, water capacities, and production and manpower requirements for successful hydraulic mining. However, they do provide enough general data on mining conditions, manpower, and equipment used to show that conditions in many bituminous coal deposits in the United States may be favorable for economical coal extraction, using high-pressure water jets. Therefore, the Bureau proposes to conduct a field investigation to determine the most appropriate natural conditions, water pressures, and equipment for successful hydraulic mining of coal beds in the United States with variable dip, thickness, and hardness.

In the past, technical personnel reviewing foreign mining reports assumed that a steeply pitching coal bed was necessary for successful hydraulic mining. Although the structure of the coal bed may be a factor in gaining assistance from overburden pressures or help in an integrated hydraulic mining and transportation system, the coal is broken mainly by the action of high-pressure, water-penetrating cracks, fissures, or cleats; therefore, the slope of the coal bed is not necessarily a determining factor in hydraulic mining.

In the past several years, articles in foreign technical publications have indicated that the mining industries of U.S.S.R. and New Zealand have been extracting and transporting coal underground by hydraulic methods. The more recent publications from Russia indicate that this method has advanced from an experimental to a commercial stage. The reported results show marked increase in productivity and recovery, along with decreased mining costs, compared with conventional mining methods previously used at the same installations.

^{1/} Work on manuscript completed July 1958.

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One Russian article published in 1956, reviewing the accomplishments of this mining method after a 4-year period, reports that the output of one mining installation reached 40 metric tons (44 short tons) per man-shift and the percentage of recovery was nearly 87 percent. Other literature sources (summarizing the information from all mines using hydraulic extraction of coal) report that, after several years of operation, monthly production (including all face operations) was two and one-half to three times greater than the monthly output of the most productive deep mines in the same area. Production costs were reported to about equal the cost of strip mining in the same areas.

Concurrent with these hydraulic coal-mining installations, the Soviet Government has established a special research institution at Stalinsk, in the Kuznetsk Basin, to study problems relating to hydraulic extraction and transportation of coal and methods of development for hydraulic mining. Also, the Siberian Mining and Metallurgical Institute has added a department to study hydraulic extraction from deep coal beds.

Basic research has been conducted to develop an index of coal hardness. From these studies the water pressure and capacity necessary to mine and transport coal have been calculated. Other investigators have designed and developed improved nozzles, monitors, special roof supports, and water pumps that can supply large volumes of water under relatively high pressures.

In New Zealand investigators have been concerned more with obtaining large volumes of low-pressure water for hydraulic transportation of coal than with developing high-pressure pumps for mining. Consequently, hydraulic mining technology has advanced little beyond sluicing and fluming coal obtained from coal pillars abandoned after conventional mining. However, according to recent information from New Zealand, plans have been made and improved equipment developed to extract coal hydraulically from a dipping coal bed.

Recent foreign publications show that hydraulic mining and transportation of coal are still in the experimental stage in Poland and West Germany, but some field investigations indicate that this method of mining and transportation has commercial possibilities.

Several countries, including Great Britain, France, West Germany, Poland, and Japan, have investigated the economic possibilities of underground hydraulic transportation of coal. It appears that the indirect method - feeding the broken coal into either a vertical or horizontal pipeline - has a greater potential than using solid-coal-handling pumps.

MINING AND TRANSPORTING COAL BY HYDRAULIC METHODS IN THE U.S.S.R.

History and Introduction

According to foreign technical publications, use of water under pressure to break and move material is not a new concept in the Soviet Union. Although detailed data on water capacities, water pressures, and productivity at mines were not revealed, peat was mined and flumed hydraulically as early as 1918.

In 1928 hydraulic equipment (after further development by the peat-mining industry) was installed at a brown-coal, open-pit mine to remove the overburden. Although these operations were reported to be successful, the use of water under high pressure for breaking the coal was not considered before 1935. This failure to use high pressures before 1935 resulted from lack of equipment capable of handling pressures greater than 500 pounds per square inch.

In 1935 (spurred by a desire to increase coal output without increasing the manpower employed at the coal collieries) Dr. V. S. Muchnik of the Leningrad Mining Institute advocated the use of high-pressure water jets for mining coal and designed the first complete hydraulic mining system. His plan proposed not only breaking of the solid coal using the kinetic energy of the water jet but also transportation of the broken coal by gravity through flumes lined with sheet steel or ditches constructed along the entries. Accordingly, under Dr. Muchnik's supervision the first underground hydraulic experiment was conducted in the Kizel Basin from 1936 to 1937.

Based upon the favorable results of this experiment, an underground hydraulic mine was designed and constructed in the Donets Basin (Urals) in 1939, but this work was interrupted by World War II. It is known that the mine was developed by sinking a vertical shaft into a steeply pitching coal bed 47 to 55 inches thick. From the shaft, entries were developed on a 5-percent grade to provide gravity transportation. The coal (after being broken from the solid face by the water jet) flowed to the main-shaft sump through a ditch constructed along the side of the entry. At the main sump coal larger than 0.02 inch was hoisted by conventional means, and the fines were delivered to the surface by a coal pump. Although this was an experimental operation, a monthly output of 6,000 metric tons was achieved by an advancing modified longwall 60 feet wide, and production reached 5.5 to 6.0 metric tons per man-shift.

Other countries (including Poland, New Zealand, and Great Britain) also have studied using water jets to mine coal and flume the broken material and are now investigating other applications of hydraulics to coal mining. However, the Soviets claim to have been the first to successfully establish a unified, uninterrupted system covering all phases of work from the active face to the preparation plant.

After World War II, intensified research in underground hydraulic mining was resumed in the U.S.S.R. by installing hydraulic equipment in the Tyrgansk-Uklony and Polysayevskaya-Severnaya mines in the Kuznetsk Basin and Karaganda area. The coal in these areas is bituminous and is reported to have a firmer structure than the coal worked in the earlier experiments. Figure 1 shows locations of the hydraulic mining installations in the U.S.S.R.

At the Soviet installations hydraulic mining comprises not only breaking and extracting coal by using high-pressure water jets but transportation of the coal-water mixture as well. This mixture may be transported either in open flumes placed on the mine floor or in ditches constructed along the entries. An alternate method is to transport the material under pressure through a horizontal pipeline to a central sump, where the coal is crushed

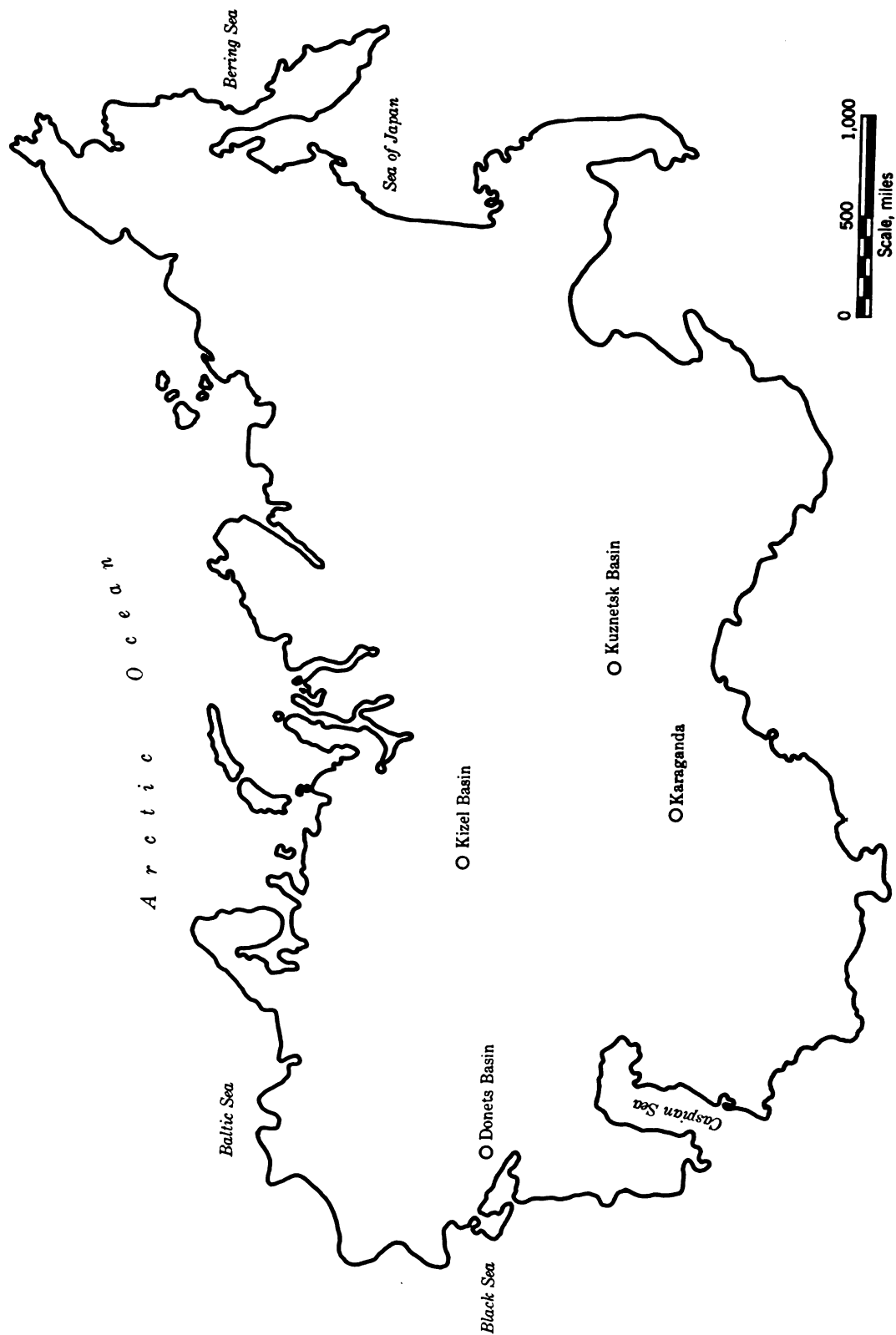


FIGURE 1. - Map of U. S. S. R., Showing Hydraulic Mining Areas.

to a top size of 2.8 inches and then pumped through a vertical pipe to the preparation plant. Because the hydraulic system is a single continuous flow process, it results in increased output, compared with conventional mining in the same area, and eliminates the need for the more costly cutting, loading, underground-transportation, and hoisting equipment. Using this mining and transportation method, however, has created complex problems that must be solved to achieve a successful operation.

Research

The interest of the U.S.S.R. in this relatively new mining method is demonstrated by its establishment of a special institute at Stalinsk (Donets Basin) to study the problems of underground hydraulic coal extraction, transportation, and mine development. A department also has been established in the Siberian Mining and Metallurgical Institute to investigate problems of hydraulic mining methods applied to relatively deep coal beds.

Many problems of underground hydraulic mining and transportation remain unsolved, but preliminary results obtained at the experimental mines have been encouraging enough to cause expansion of the method from the experimental stage to commercial-scale application in the Kuznetsk, Karaganda, Donets, and other coal basins.

The research institutions do basic research on determining coal hardness, water pressures, and capacities needed to break and transport the coal, nozzle and monitor designs, roof supports, and coal pumps. Prof. M. M. Protocyak developed a hardness scale for all formations. The scale ranges from 0.3 for soft, wet soil to 20.0 for hard quartzite or basalt. The literature does not describe in detail the apparatus used to make these determinations.

To determine the minimum water pressure (P) necessary to break coal effectively without preshooting, N. F. Tayapko of the VNIIGidrougol' Institute derived an equation for determining these values as a function of coal hardness. The equation ($P = fH$) was developed using a constant (f) equal to 50 atmospheres ($50 \times 14.7 = \text{p.s.i.}$) and the hardness (H) of the formation. Since the hardness of any coal bed may vary somewhat, even within a narrow area, because of changing bed characteristics or extraneous intrusions within the bed, these hardness values can only be regarded as approximations. However, this equation has proved to be a reliable guide at Soviet installations, and the only time that it is necessary to apply corrective coefficients is when the bed has been broken previously by overburden pressures or geologic disturbances.

The water pressure necessary to mine successfully is determined more by the cleavage planes in the bed and squeezing induced by overburden pressures than by resistance to crushing or hardness of coal. When cracks or fissures are created, either by geologic disturbances or preshooting, the water pressure needed to extract the coal can be decreased considerably. As an example, the coal mined hydraulically at the Tyrganskies-Uklony colliery had a hardness index of 1.5, requiring 75 atmospheres or 1,100 p.s.i. according to the pressure equation; however, owing to previous geologic disturbances that had caused large fissures in the coal bed, hydraulic mining was successfully applied at

this installation, using a pressure of only 588 p.s.i. or 46 percent of the calculated value.

Along with pressure determinations, equations have been derived for determining the energy consumed in breaking the coal, the capacity of the hydraulic monitor, and nozzle design. From production studies it was determined that the hydraulic energy (e) consumed in breaking 1 ton of solid coal was 10 kw.-hr. and for breaking 1 ton of fissured coal, 5 kw.-hr. With these data, the total energy used in breaking coal can be determined from the equation

$E = \left(e \frac{P_2}{P_1} \right)^2$, where P_2 is the nozzle pressure of the water jet and P_1 is the pressure of the jet at the coal face, both expressed in atmospheres. The value P_2 will be greater than P_1 by the amount of energy lost between the nozzle of the monitor and the coal face.

Another equation was derived for determining the ~~maximum~~ amount of coal (in tons per hour) that could be extracted by any monitor. This equation is expressed as $A = \frac{QP_2}{36.7E} \times K$, where Q is the water consumption in cubic meters per hour and K is a coefficient assumed to be 1.8 in retreat mining and 1.0 for development work.

To further reduce the cost of hydraulic mining by decreasing water requirements, several investigators have studied the design of water nozzles. According to their findings, the hydraulic jet has three different phases of action along its length of path that differ from each other in length, cross-sectional area, speed, thrust, and degree of air mixture.

The first phase of action is in the immediate area of the nozzle. Here the jet is dense and compact, very little air has mixed into the stream, and there is a gradual decrease in speed and thrust. In the second phase the cross-sectional area of the jet has increased, the stream has become mixed with air to a considerable degree, and speed and thrust have dropped sharply. In the third and final phase the jet stream is composed of individual sprays, and there is a continuing decrease in speed and thrust until each spray strikes the face.

Transportation

Flumes

The U.S.S.R. has done considerable research on ways to transport the broken-coal and water mixture from the active face to the preparation plant. Initially, ditches constructed along the left side of the entries on an inclined grade from the main sump to the active working face were used at the mines. However, these ditches had a high frictional resistance, and grades over 7 percent and a large volume of water were needed to overcome this resistance and move the broken product.

To mitigate this problem, steel channels (trapezoidal in cross section) were constructed with a height of 12 inches and a width of 16 to 20 inches at the bottom. Although it was customary to place these channels on a grade of 4 to 5 percent at the mining installations, large volumes of coal-water mixtures have been transported through these channels placed on a grade of 3 percent. Practical experience has shown that the maximum capacity of the 16-inch-wide channel is 1,321 gallons per minute, whereas that of the 20-inch-wide channel is 2,201 gallons per minute.

It has been determined also that the minimum water velocity at which a mixture will flow in a steel flume is 3.28 feet per second. To avoid the possibility of stoppage, it is customary to maintain a minimum velocity of 4 to 6 feet per second. The water velocity in a flume can be determined by the equation $V = C\sqrt{R(1-0.012)}$, where C is a coefficient determined from tables for pure water, R the hydraulic radius, i the channel gradient, and 0.012 the coefficient gradient for coal-water ratios between 1 and 3 and 1 in 10.

Along with research in flume transportation, investigators at the Lenin-grad Mining Institute have experimented with glass-lined flumes. According to their findings, it is possible to move a coal-water mixture in a glass-lined flume on a 2-percent grade.

Pipelines

The U.S.S.R. has done considerable research on transporting coal hydraulically through pipelines. It has been determined that the resistance to flow depends upon the consistency of the slurry. Friction losses during transport are those of pure water at an input equal to that of the slurry plus a certain constant depending upon the coal-to-water ratio. These constants will be 0.012, 0.01, and 0.007 for solid-liquid ratios of 1:2.5, 1:4, and 1:8, respectively.

At present, all coal is reduced to 2.8 inches by hammer crushers before entering the main sump. Owing to excessive degradation of the coal by the hammer crusher, the VNIIGidrougol' Institute is developing a cone-type crusher known as KDM-4 that will have a capacity of 150 metric tons per hour. The driving wheel of the coal pump generally used has three openings, each with a maximum diameter of 2.8 inches that limits the coal-feed size.

A high-pressure, centrifugal, two-stage coal pump (model 6-NUV) is used to hoist the coal-water mixtures. This pump, with an inlet diameter of 5 inches, has a capacity of 1,321 gallons per minute when operating at 1,450 r.p.m. By series connecting the two stages only one electric motor is required. The power requirement for the coal pump is 450 to 500 kw. Experimental data showed that the ratio of coal to water varied from 1:1 to 1:10, occasionally exceeding 1:10. When jigs or concentrators are used in the surface preparation plant, optimum operating procedures are achieved when the coal-to-water ratio falls within the range 1:2 to 1:4.

In the first experimental operation the coal inlet pipe was placed horizontally along the bottom of the sump, but stoppages proved that this method

was unsatisfactory. To avoid blocking, an unsuccessful attempt was made to loosen the coal mass by connecting the high-pressure waterline to the inlet pipe, but expenditure of large volumes of high-pressure water curtailed output at the face; therefore, this method of combating stoppages was abandoned in favor of a vertical coal pickup. To regulate consistency of the inlet coal-water mixture, the intake pipe was raised almost to the surface of the sump before the pump was started. After water had been pumped for a short time, the pipe was gradually lowered into the coal sump by hand winches. This procedure facilitated starting the pump and prevented blocking the intake line. To prime the pump, the high-pressure waterline is connected to the discharge of the coal-water pump. This procedure has been most effective after the pumps have been stopped for short periods but can be used to flush out the discharge line after the pump has been stopped for any length of time.

Because the coal-water mixture tends to pile up in the flumes - thus forming an irregular flow to the sump - the pumping installation should be designed for the maximum rate of flow. Originally, rectangular sumps were constructed, but experience has shown that in long sumps the coal is not drawn into the pump inlet pipe from the farthestmost sections of the sump. The sumps now in use at the active installations are usually 12 feet wide by 12 feet long and about 5 feet deep. It has been a practice in the past to construct an auxiliary sump and fill it with mine water to avoid running the coal pump at less than desired capacity, but pumps equipped with regulators are now being developed that automatically adjust the capacity to the rate of mixture. Experiments also have been made to regulate the pump capacity by fitting a valve on the intake side, thus allowing the pump to take up to 12 percent of air into the system.

Roof Control

In the first experimental operation, a hydraulic monitor was placed near the clean coal face under a rigid roof shield. At that time it was planned that all mining operations would be conducted under a protective, rigid shield covering. This type of support had to be abandoned, however, because of difficulties in operating the shield. In conventional mining, forepoling or laying of rigid roof support can be accomplished easily, owing to the relatively straight riblines and level roof. However, when hydraulic methods are used, the coal does not break uniformly at the top, and the shield tends to catch on the clinging top coal. This places a greater stress on some parts of the roof shield unless manual labor is used to remove the top coal.

A flexible shield of metal screening laid in four overlapping layers has been used. Two layers of screen cloth are placed lengthwise and two crosswise. The screen cloth with a mesh opening of 0.8 by 0.8 inch and a wire diameter of 0.08 inch has a strength of 85,300 p.s.i. It is delivered to the mine in 3.28-foot widths and 49- to 76-foot lengths. When mining is done in steeply pitching coal beds, a horizontal layer of coal is removed at the upper sublevel, and the screen is laid directly on the coal floor with the screen ends overlapping both the hanging wall and foot wall. Although this screen may offer some protection from overhanging roof rock, the literature sources report that it is used mainly to avoid mixing the roof strata with the coal.

Using either the rigid or flexible shields necessitates increased manpower at the mining operation and has been virtually abandoned in favor of using wooden sets previously assembled on the surface or steel arches. These can be quickly placed and withdrawn, and use of wooden sets connected with ties 7.56 to 9.84 feet long has become standard practice.

Mining Methods

In 1952 hydraulic equipment was installed in the Tyrganskie-Uklony mine to meet a planned production of 500 metric tons per shift. Since precautions had to be taken with this coal bed to combat spontaneous combustion, it was decided to develop a block containing only enough coal for 6 months of mining operations.

As shown by figure 2, the mine was developed by sinking two wooden supported shafts 1,350 feet apart into a coal bed pitched at an angle of 65° to 70° and varying between 18 and 66 feet in thickness (averaging 33 feet). Strong roof and floor conditions were present at this mine. The shafts were constructed to serve a dual purpose - provide an entrance (1) into the block of coal for immediate mining operations and (2) into the adjacent areas of coal for future mining operations. Although the literature sources do not mention the maximum depth of this operation, the block of coal between the two shafts was developed by driving main levels, separated 144 feet vertically, on a 5° rise from the intake shaft.

For ventilation and transportation purposes, foot- and hanging-wall raises were driven between main levels every 180 to 360 feet. The footwall raise, which was used for transporting the coal-water mixture, was developed to have a circular cross section and supported by yielding metal arches or metal supports. The hanging-wall raise, supported by wooden timber sets, was divided into compartments for transporting men and supplies. These raises were connected by crosscuts dipping at 5° toward the footwall raise. To further develop this large block into small minable blocks (18 feet thick and 90 feet long) sublevels were driven on a rise of 5° from the footwall rise and connected by crosscuts for ventilation purposes.

After completion of all development work, the blocks were extracted by retreating toward the intake shaft. The coal between main levels was mined in descending order. To take advantage of overburden pressures, the coal between the sublevels was mined in ascending order, allowing the area to cave fully.

High-pressure pumps on the surface delivered the water under pressures of 515 to 588 p.s.i. to the mining operation through cast-iron pipelines. The pipes from the surface installation to the main levels were 8 inches in diameter, whereas those extending into the active mining areas were 4 inches in diameter. To facilitate mining, a hydraulically operated control valve was developed and installed near the monitor. At first this valve was operated manually, requiring an attendant while the monitor was in use, but now with the hydraulic valve operated by remote control the operator is free to examine the face at any time.

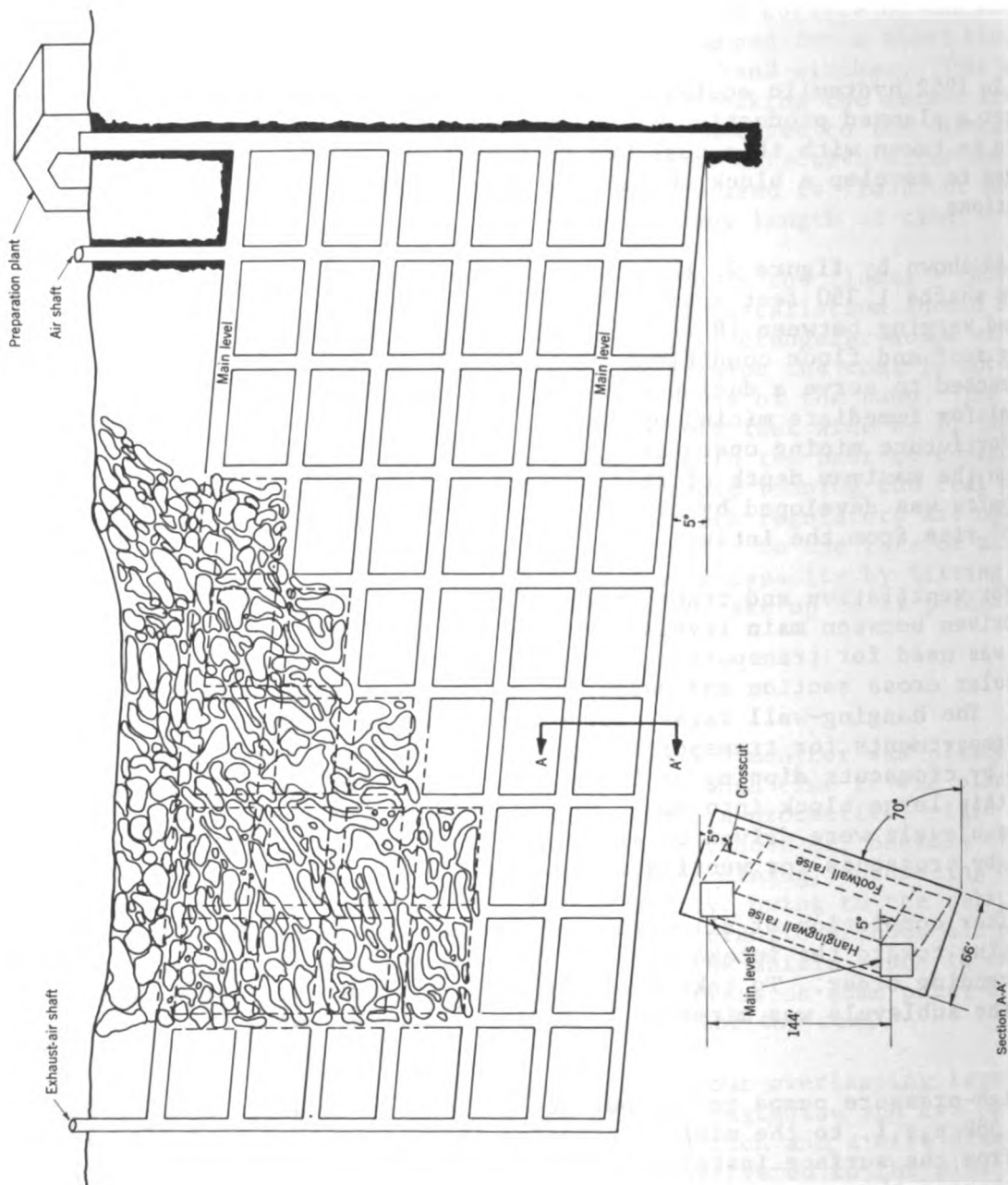


FIGURE 2. - Russian Hydraulic Mining Method Adopted at the Tyrgansk-Uklony Mine.

Actual mining operations were conducted as follows: A hydromonitor, consisting of a barrel and nozzle, was placed 4 to 6 feet from the prepared face, and a stream of high-pressure water was directed against the coal near the floor. The jet action produced cracks or fissures around the impact point, and the high-pressure water penetrating into these cracks broke lumps of coal from the solid face.

Two types of monitors, Gn-1 and RGM-1, were used at this operation. The former was developed for use in steeply pitching coal beds, whereas the latter was intended for use in more level coal beds. Each monitor can be rotated 360° vertically and 140° horizontally. Although they were designed by the Kuznetsk Coal Institute (KusNIUI) for different types of operations, they both proved effective at the Tyrganskies-Uklony mine. Two types of nozzles, having diameters of 0.76 and 1.08 inches, respectively, were used successfully with the two monitors and found to be interchangeable. Figure 3 shows a typical underground hydraulic monitor installation.

Since hydraulic mining requires constant lengthening or shortening of the 4-inch-diameter water-feed lines, depending upon whether retreat or development work is being done, the feed lines were constructed in 12- to 14-foot section lengths and joined with rapidly installed couplings developed by KusNIUI. The coupling, two half collars of cast steel attached to the welded flanges of the sections and tightened by inserting a wedge-shaped cotter pin, permits changing the length of the feeder line in 4 to 5 minutes, using only two men. KusNIUI also developed special pipe bends for this mine that provided directional changes up to and including 90°.

In the latter part of 1952 the mine attained a peak production of 600 metric tons per shift or approximately six times over the average production from conventional mining in the same district. This remarkable achievement was attained despite the incomplete status of the surface-plant installation that undoubtedly retarded underground operations. Figure 4 shows a flow diagram of the hydraulic movement of coal in the Tyrganskies-Uklony mine.

A Russian article reviewing this work after 1-1/2 years of operations, reports that the coal recovery was 87 to 89 percent, considerably more than that achieved by conventional mining. Production costs were approximately one-half those of conventional mining and nearly equal to strip-coal-mining costs in the same district. In 1954 the monthly output, including all face operations, was 2-1/2 to 3 times that of the best mines in the district using conventional equipment.

Based upon the success of hydraulic mining at the Tyrganskies-Uklony mine and to experiment further with this mining method, hydraulic mining equipment was installed in the Polysayevskaya-Severnaya mine in 1953. Here the coal bed was 70 to 86 inches thick and dipped at an angle of 6°. The roof and floor were rather weak. The coal, with a hardness of 1.3, was characteristic of the coals in the district. The bed did not contain cracks or fissures, and pre-shooting was necessary before the coal could be mined with a water pressure of 470 to 588 p.s.i.



FIGURE 3. - Typical Underground Hydraulic Monitor Installation.

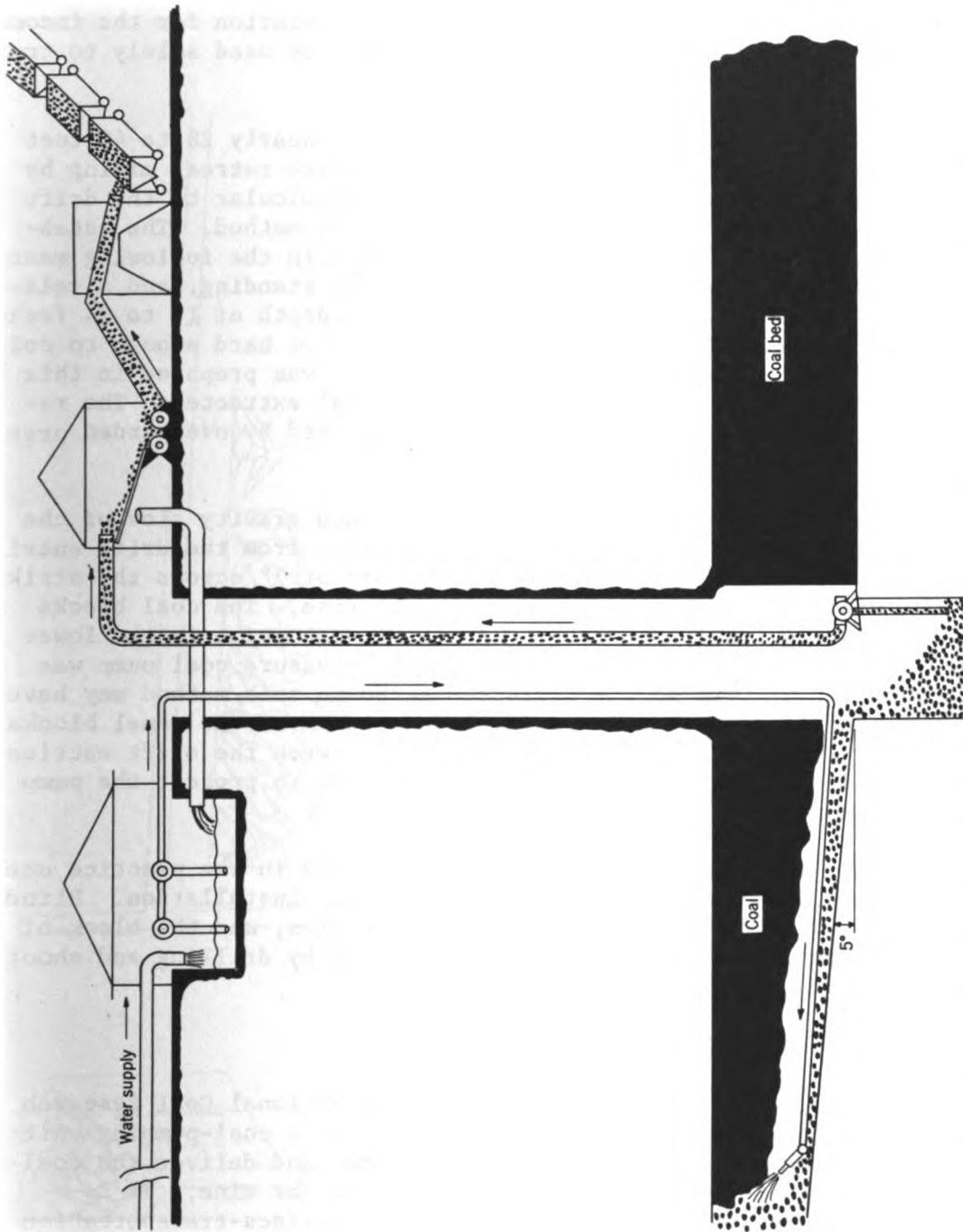


FIGURE 4. - Flow Diagram of Hydraulic Movement of Coal in the Tyrganskie-Uklony Mine.

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Although various schemes have been used to develop and mine sloping coal beds, this mine was developed into sections, using three variations of drift-and-panel entries. In each method two drifts were developed on a gradient of 1 foot in 8 feet across the strike of the coal bed for 1,650 feet. The upper drift was used to transport men and supplies and as a location for the incoming high-pressure waterlines, whereas the lower drift was used solely to transport the outgoing coal-water mixture.

In one method of extraction, large blocks of coal nearly 28 to 48 feet wide and 300 to 360 feet long were established for future retreat mining by developing panel entries 13 feet wide and nearly perpendicular to the drift entries on 40- to 60-foot centers. Figure 5 shows this method. The established blocks of coal were prepared for retreat mining in the following manner: A solid coal stump 3 feet long toward the gob was left standing, and a relatively short block about 6 feet long was drilled to a depth of 17 to 24 feet and blasted lightly to develop fissures or cracks but not hard enough to collapse the coal bed. After half of each adjacent block was prepared in this way, the high-pressure water was turned on and the coal extracted. The remaining fender or pillar (undrilled) was partly recovered by overburden pressure that crushed the coal out into the entry.

Another method employed at this operation combined gravity flow of the mixture from the panel entries with pumping of the coal from the drift entries. As figure 6 shows, the drifts were developed on a dip of 7° across the strike of the coal bed with panel entries developed to the rise. The coal blocks were established as previously described. At the lowest point in the lower drift entry a coal sump was constructed, and a high-pressure coal pump was installed to pump the mixture to the surface. Although this method may have some advantages when excess water is recirculated, parts of the panel blocks adjacent to the drift entries and the coal pillars between the drift entries cannot be recovered by hydraulic means but must be left to protect the pump and pipeline equipment.

A third method, which differed from the second only in the practice used to develop crosscuts, was successfully employed at this installation. Blind, staggered crosscuts were developed from the panel entries, and the block of coal remaining between the panel entries was fractured by drilling and shooting from the crosscuts in a radial pattern.

Future Hydraulic Research

According to recent technical publications, the National Coal Research Institute in Moscow has developed a single, high-pressure coal-pumping unit that can pump coal from a depth of 1,640 to 1,960 feet and deliver the coal-water mixture to a preparation plant 3 to 5 miles from the mine. It is claimed that this system saves both underground- and surface-transportation costs.

To provide enough lighting in the active mining areas the Tomsk Electro-Mechanical Works has developed a hydraulically powered lighting unit for the hydraulic monitor. This unit has a small hydraulic turbine and an individual generator for a single electric light bulb at the monitor.

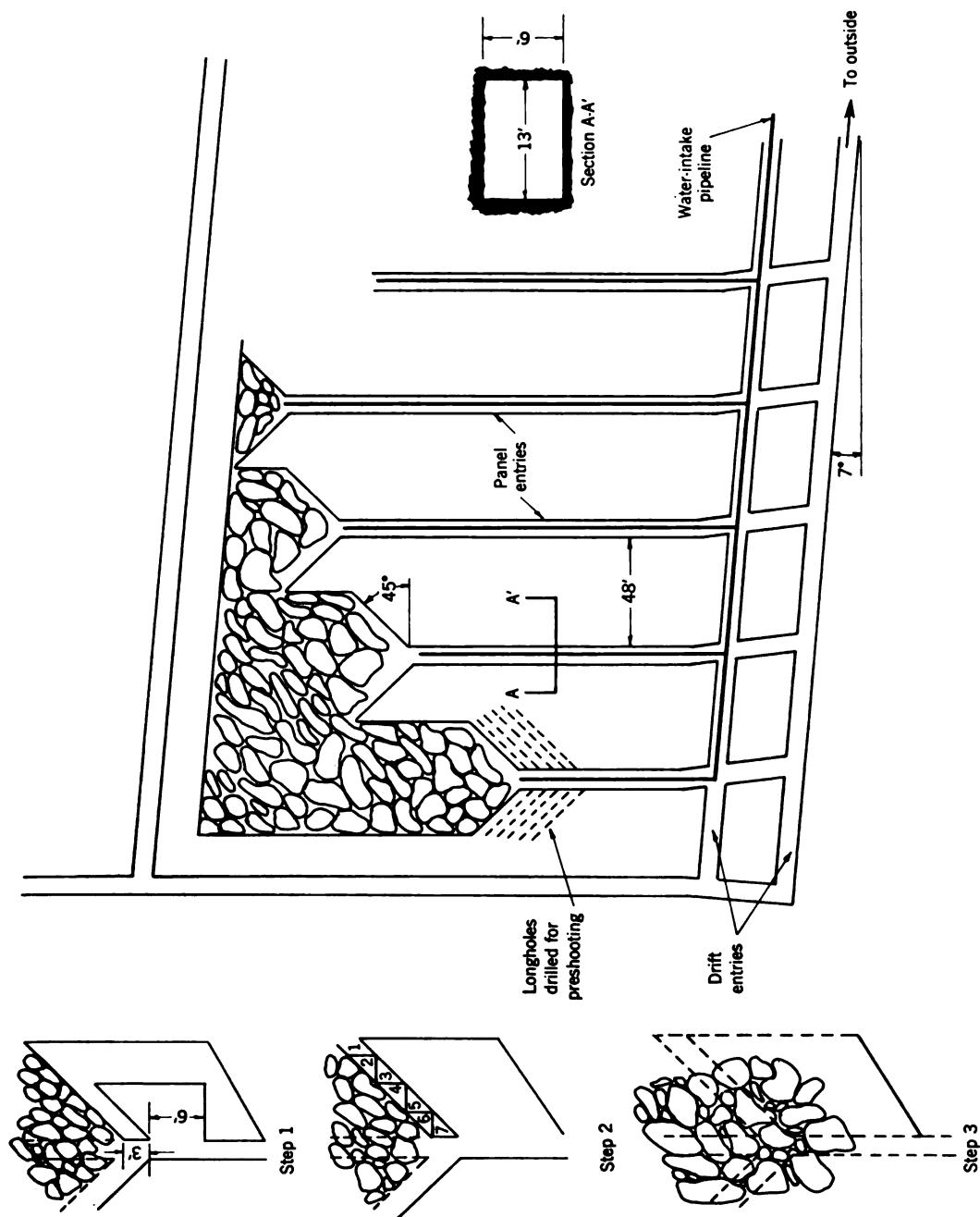


FIGURE 5. - Gravity-Flow, Hydraulic Coal-Transportation System Adopted at the Polysayevskaya-Severnaya Mine.

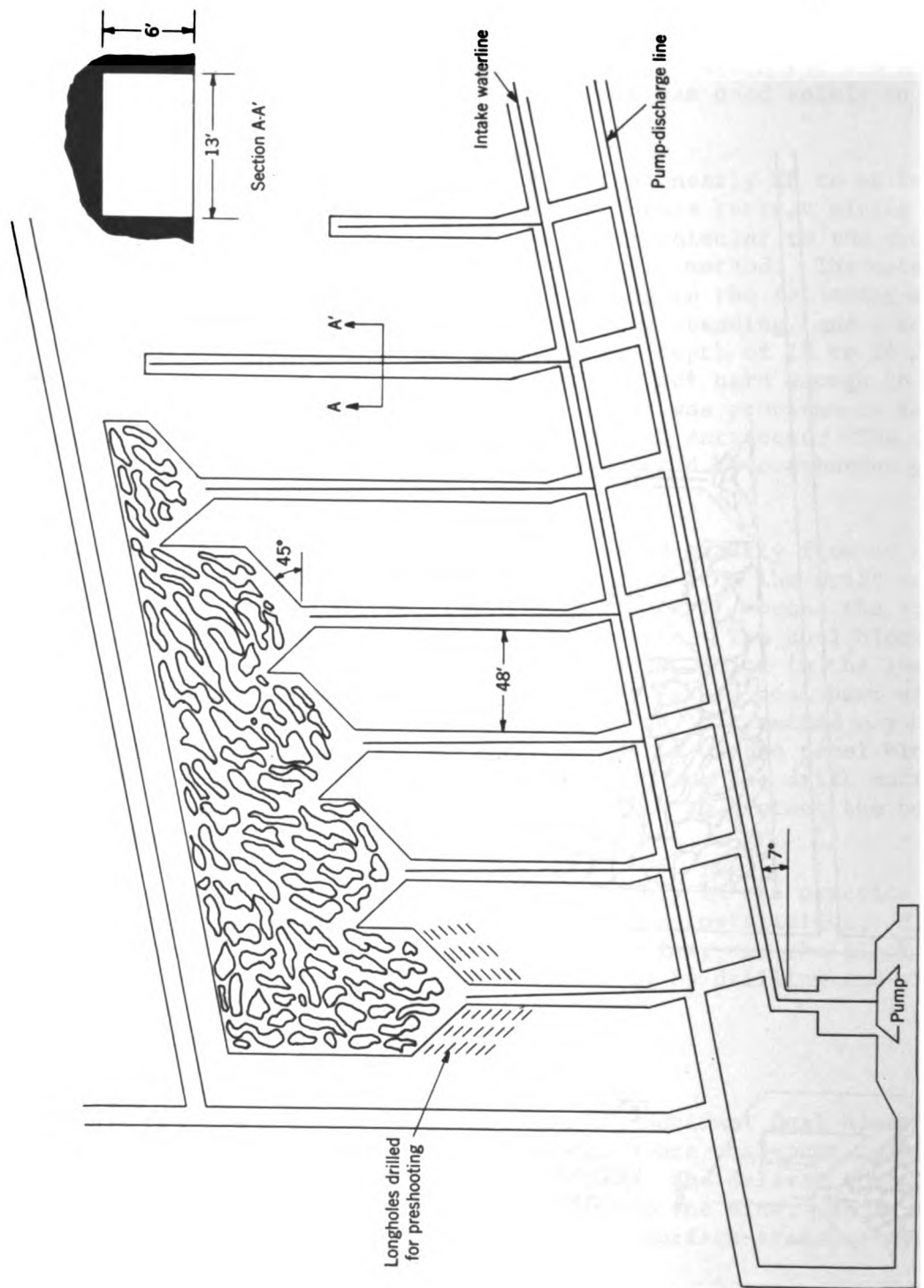


FIGURE 6. - Russian Hydraulic Mining Method Adopted at the Polysayevskaya-Severnaya Mine.

Owing to the achievements at the two hydraulic installations, 69 underground units were scheduled to start producing by this method during the current 5-Year Plan (1956-60). According to the plan, the total production was expected to rise from approximately 250,000 metric tons in 1955 to 1,500,000 tons in 1956 and 12,500,000 metric tons in 1960, approximately 2 percent of total planned output.

MINING AND TRANSPORTING COAL BY HYDRAULIC METHODS IN NEW ZEALAND

History and Introduction

Hydraulic mining of coal in New Zealand evolved from hydraulic methods developed by the gold-mining industry of that country. Before 1954, when the New Zealand States Mining Department constructed surface and underground installations to study mining and transporting coal hydraulically, most hydraulic coal operations had been undertaken by cooperative groups of former gold-mining operators with experience in the hydraulic mining and dredging of ore. Their source of coal was the pillars left after conventional mining. Owing to the small size of these installations and the limited capital of the operators, much of the equipment used had been salvaged from abandoned hydraulic gold-mining operations.

Extracts from a report issued by the New Zealand States Mining Department indicate that as early as 1891 an operator supplying fuel to a gold-dredging operation used hydraulics to remove the overburden and extract the coal from an open-pit mine. The broken coal was transported to the point of consumption in flumes. Since this operation was in a rather remote area, the advantages of this novel means of coal mining and transportation generally remained unnoticed by the coal industry of New Zealand until 1920. In that year a coal-mining company constructed an outdoor flume to move their coal from the mine to the main roadway, a distance of one-fourth mile. This method of transportation proved so profitable that the following year the length of the flume was extended to 3 miles.

The coal-mining industry in the immediate area was highly impressed by the project's economics, and the following year two additional coal companies built flumes to transport their coal to the tramline or a main roadway.

In 1924 a large coal-mining company constructed a wooden flume 7-1/4 miles long and lined with sheet-iron plates. The flume traversed irregular terrain and had sharp bends, causing severe degradations of the large lumps. At the flume discharge point, considerable fine coal was lost, owing to incomplete removal of solids from the transport water. The operation was not a success and after 2 years was abandoned.

All coal companies constructing hydraulic transportation systems for coal copied the construction of previously successful installations, and no new technologic advances were made until 1927. In that year water was used at an underground operation to extract the coal pillars abandoned during previous mining and to flume broken material from the working area to surface storage bins some distance away. At the same time another coal-mining company

constructed a similar mining and transporting system. At this operation a surface flume 7-1/2 miles long transported the coal from the mine to storage bins. Here, too, the surface flume traversed irregular terrain, and grades varying from 1 foot in 33 feet to 1 foot in 125 had to be overcome. Glass, steel, rubber, and wooden flume liners were tested. The liner finally selected consisted of 3-inch wooden blocks with the wood grain perpendicular to the direction of flow.

In the next 20 years, although 2 more coal-mining companies began using low-pressure water jets to recover previously abandoned coal pillars and sluicing the coal in flumes from the underground area to outdoor storage facilities, no major technologic advancements were made in hydraulic coal mining.

Before 1947 all hydraulic coal mining was centered in areas near an adequate supply of water that could be obtained by gravity. In 1947, at the Happy Valley coal mine a water-supply reservoir was constructed 50 feet below the level of the coal bed. To furnish the water requirement of 6 cubic feet per second under a positive head of 86.8 p.s.i. at the active face, a 150-hp. diesel pump was installed at the water source. Using a completely integrated hydraulic mining and transportation system, output reached 60 tons per man-shift. This new concept, using a pump to supply water under pressure, permitted some small coal-mining operations to extract the coal hydraulically where it would have been uneconomic to provide water by gravity. Although several operators used the pumping technique, no attempt was made to obtain higher water pressures than those used at the Happy Valley installation.

In 1954 the New Zealand States Mining Department decided to study methods of mining and transporting coal hydraulically and built surface and underground installations for this purpose. Water flowed by gravity to the main mine adit through a 30-inch-diameter pipe. From the 30-inch-diameter pipe the water flowed through 12-inch-diameter pipes laid in the main entries. Eight-inch-diameter pipelines served the main working areas, whereas 4- to 6-inch pipelines were used to bring the water to the working face. The system supplied 8 to 10 cubic feet of water per second under pressures ranging from 43.4 to 81.1 p.s.i. at the active face.

Mining Methods

Development

Except for a recently established mine, all coal-mining operations in New Zealand have followed a similar plan of development. The coal beds rising from the outcrop averaged nearly 12 feet in thickness. Two entries 7 to 12 feet wide were driven up the rise on 66-foot centers. From these entries rooms or sublevels, 6 to 10 feet wide and extending to the mining limits, were also driven on 66-foot centers. Crosscuts connecting these sublevels likewise were developed on 66-foot centers. This method can be compared to the block system of mining in the United States wherein a series of large coal pillars is formed for future retreat mining. Figure 7 shows a plan view of a typical mining installation in New Zealand.

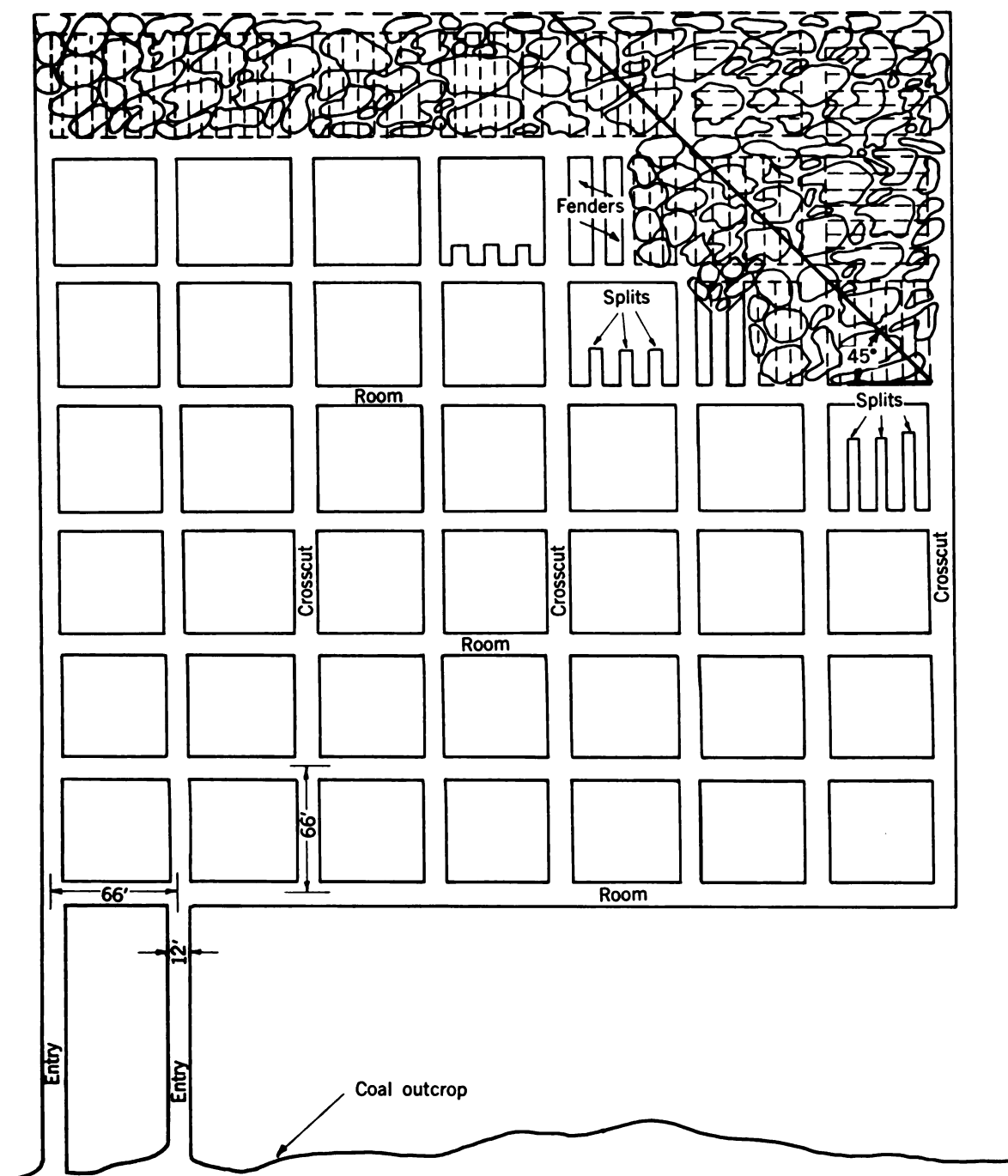


FIGURE 7. - Typical Hydraulic Mining Method Used in New Zealand.

The conventional practices of undercutting the coal face and preshooting are followed in development and to a small extent in retreat mining. Although under unusual circumstances the coal must be undercut by hand, it is common practice to wash out a kerf in the soft coal bands near the bottom of the bed, using the low-pressure water jet. This kerf is extended to a depth of 4 to 6 feet, depending upon the hardness of the coal.

To preshoot the coal face, holes are drilled to a depth of 4 to 6 feet, using either compressed air or electric or hand operated rotary drills. Owing to the small size of the mining operations and the limited amount of capital and equipment available, most drilling is done using a hand-operated drill, commonly called a breast auger in the United States. When an electric drill equipped with tungsten-tipped carbide bits is used, a complete face can be prepared in about 8 minutes. The shots are fired separately to conform with the mining laws. It is a common practice in small operations to remove the broken coal with the low-pressure water jet, while waiting for the fumes to disperse between shots.

A face can be drilled, shot, and loaded out in about 20-45 minutes by using the monitor intermittently during the firing cycle; this practice is not widespread throughout the industry. After the blasting round is completed and the loose coal removed, it is usually necessary to trim or square the face with a pick. The cycle is then repeated.

In development, timbers are placed along the centerline of the workings and approximately 5 to 10 feet apart, depending upon roof conditions, to afford roof control and support for the waterlines. Although this method is not as fatiguing to the worker as the conventional system of mining, placing the timbers up narrow workings is very arduous. To facilitate moving timbers, pipelines, and other supplies, some larger operations have installed monorails extending from the mine entrance to the active face and mounted to the roof rock with roof bolts.

Pillar Work

After the mine is completely blocked out as heretofore described, retreat mining begins at the highest point and proceeds toward the adit. Two successful methods of retreat mining have been developed. In both methods the pillars are split by driving working places 3 to 5 feet wide and 5 feet high. Experience has shown that places developed to these dimensions need no roof support. Since the workings are narrow, the miners are not endangered by sudden roof falls in the gob area that may tend to flow into the active workings.

With one mining method, the coal pillar is divided into four parallel fenders by driving three splits on 16-1/2-foot centers, advancing toward the rise; this method permits mining operations simultaneously in three places. As the small fenders are recovered by retreat mining, the coal is shot down and allowed to accumulate toward the lower level. After advancing the face for a distance of 6 to 7 feet or until the split is filled with broken coal, the mass of broken coal is washed out of the split into the lower level. The coal is mined in this way until the entire pillar is removed. One of the main

disadvantages of this method is that coal is allowed to accumulate in the lower sublevels, resulting in an intermittent feed to the main coal flumes. Following a period of maximum recovery from the coal pillars, all available water is required to move the coal mixture in the flumes to the outside, thereby making the actual coal mining sporadic. The coal pillars can be mined by retreating either on an angle or in a straight line. Experience shows that better roof control can be maintained if the pillars are retreated on about a 45° angle.

In the second method the pillars are recovered by driving splits parallel to the coal strike, starting at the top of the pillar and retreating toward the lower level. Since it is necessary to leave the last coal fender to protect the workmen and equipment in the next lower level, only about 80 percent of the coal is recovered by this method. Another undesirable feature is that if there is a complete roof closure, common in areas previously mined by conventional methods, the operator must resort to the first method to recover the coal and equipment. Consequently, this second method is seldom used owing to the loss of coal in the small coal stumps left and the probability of losing mining equipment through cave-ins.

In both methods, waterlines (4 inches in diameter) are extended to each separate split. To increase the water velocity, the pipelines are reduced to 2 inches in diameter from the entrance to the split to the working monitor. In most instances, the water monitor consists of 2- to 3-foot, high-strength steel pipe, an elbow, and a section of 2-inch pipe. To rotate the monitor both vertically and horizontally, the nozzle section of the monitor is connected to the high-pressure line by an elbow.

To provide a completely reliable cutoff point for the high-pressure water in case of a total roof closure and to permit the workmen to adjust the quantity of water, main valves are provided in a safe area behind the active pillar workings. These valves must be opened and closed slowly, or the waterlines will burst.

Currently, two types of monitors are used. For entry-development work, the monitor consists of a rubber coupling with a 4-inch-diameter nozzle. This special coupling enables the operator to rotate the monitor through 360° both vertically and horizontally. The arrangement previously described in mining the splits has been found to be the most successful to date. Attempts have been made to further reduce the nozzle size but without success.

Water Supply

Although using water under pressure has proved to be a successful method for breaking coal away from the solid face both in development and retreat mining, the original purpose for supplying this water to the face was to provide increased water capacity as an aid in transporting the broken product cheaply and efficiently. Therefore, no attempt has been made to increase the water pressure above 90 p.s.i. Before 1947 most equipment used in mining and transporting coal hydraulically has been salvaged from the abandoned hydraulic gold-mining operations. The salvaged pipeline included a wide variety of types and

sizes - straight-riveted, spiral-riveted, welded and galvanized steel pipe, and cast-iron pipes. The joints included loose flanges, cast flanges (for cast-iron pipes), welded and riveted flanges, and a simple slip-on joint that could be made in the field by wrapping bitumen-impregnated brattice cloth around one end of a pipe and forcing this into the "belled-out" end of another pipe. This out-of-date equipment very likely could not handle water under high pressure and probably has discouraged any investigations using pressures over 90 p.s.i.

Before 1947 all water used in both mining and transporting coal was obtained by gravitational methods, and it had become a common practice to construct earthen dams across streams and direct the overflow through ditches, wooden flumes, and wooden pipes to the area of operation. Most water transported to the mine flowed through open troughs or flumes. To avoid sand or floating materials being carried to the monitors, settling boxes were built near the mine. In addition to providing an area for settling out sand, entrapped air was eliminated from the high-pressure waterlines by tapping these boxes below the water level. Since 1947, when pumping installations to supply water from below the coal level and the recirculation of mine-water were first used, the operations have been more successful both in output and percentage of recovery.

Although some operators have continued mining during extreme drought when the water supply was very low, experience has shown that each active development place requires 1/3 cubic foot of water per second for mining and 1 cubic foot per second for each active pillar split. This increased requirement for pillar operations is due more to the large quantity of broken coal that must be moved than to actual mining of the coal. Since the workmen must spend a large percentage of their working time moving the pipelines and timbering, all active working places do not require water continuously, and it is not likely that they will require the maximum amount at the same time. Owing to this intermittency of the mining, it has been estimated that a mine with 20 working places will not require more than 8 cubic feet of water per second.

Future Hydraulic Mining Plans in New Zealand

According to recent information received from New Zealand, hydraulic mining plans have been formulated and equipment has been developed to produce 1,000 tons of coal daily from a dipping coal bed. The coal is 15 feet thick. To produce the planned tonnage, 30 active working places probably will be required. Although the method of coal extraction will not differ markedly in principle from the previously described methods, the mining plan is rather unique. One of the major advantages ascribed to the plan is that it permits using combined hydraulic mining and hydraulic transportation to extract coal from a dipping coal bed wherein initial development is started some distance from the outcrop.

Before any mine-development work is undertaken, the entire mining area will be core-drilled to determine the exact deposition of the coal bed. Two vertical shafts will be sunk approximately 150 feet apart to intersect the coal bed at a depth of 300 feet. A coal and water sump will be constructed

in the coal bed near the intake air shaft and will house the vertical lift hydraulic coal pump and coal feeders.

Development

Where the shafts intersect the coal bed, they will be connected by an arched or circular roadway built around the shaft pillar, as shown in figure 8. Initially, the entries will be developed using a small-diameter waterline capable of supporting only one hydraulic monitor.

As the entries advance, positive ventilation will be supplied to the working face by forcing air from a blower fan through a large-diameter pipeline laid along the entry. When the first block of coal is developed by driving a connecting crosscut, a water-powered auxiliary fan will be placed in the crosscut, and the large-diameter pipeline will become a carrier of water to the hydraulic monitor. A smaller diameter pipeline connects the monitor to the large diameter pipe. After the first block of coal is developed, the operation will be repeated to develop the second block using the large diameter pipeline as a source of ventilation first and later to transport water to the monitors.

From the circular roadway narrow, arch-shaped entries will be developed in a radial pattern up the rise to a predetermined point. To effect this development, a high-pressure water jet (or preshooting) followed by low-pressure water extraction (30 to 100 p.s.i.) will be used. Preliminary design drawings have been prepared for an entry-driving machine having a full-face rotary boring head powered by water under high pressure.

Since only a very small amount of coal will be removed in the development of entries, it is anticipated that little or no roof support will be necessary. To counteract any unexpected roof problems, timber sets or single vertical wooden posts placed on close centers will be used. For ventilation and to provide future roadways, the entries will be connected by crosscuts at 200-foot intervals.

After the entries have been developed to predetermined limits, the large block of coal adjacent to the boundary line will be cut into coal pillars by driving narrow rooms on 66-foot centers. After all rooms have been developed to the boundary line, half of each adjacent coal pillar will be removed on the retreat.

Retreat Mining

If fissures or cleats are present in the coal or if it has been broken by geological disturbances, the pillars will be removed, if possible, using high-pressure water without preshooting. If blasting is required, the long-hole-pulsed-infusion blasting technique will be used. Even when long-hole blasting (shown in fig. 9) is applied, it is expected that the entire pillar of coal can be extracted without moving the monitor operator beyond the supported roadway.

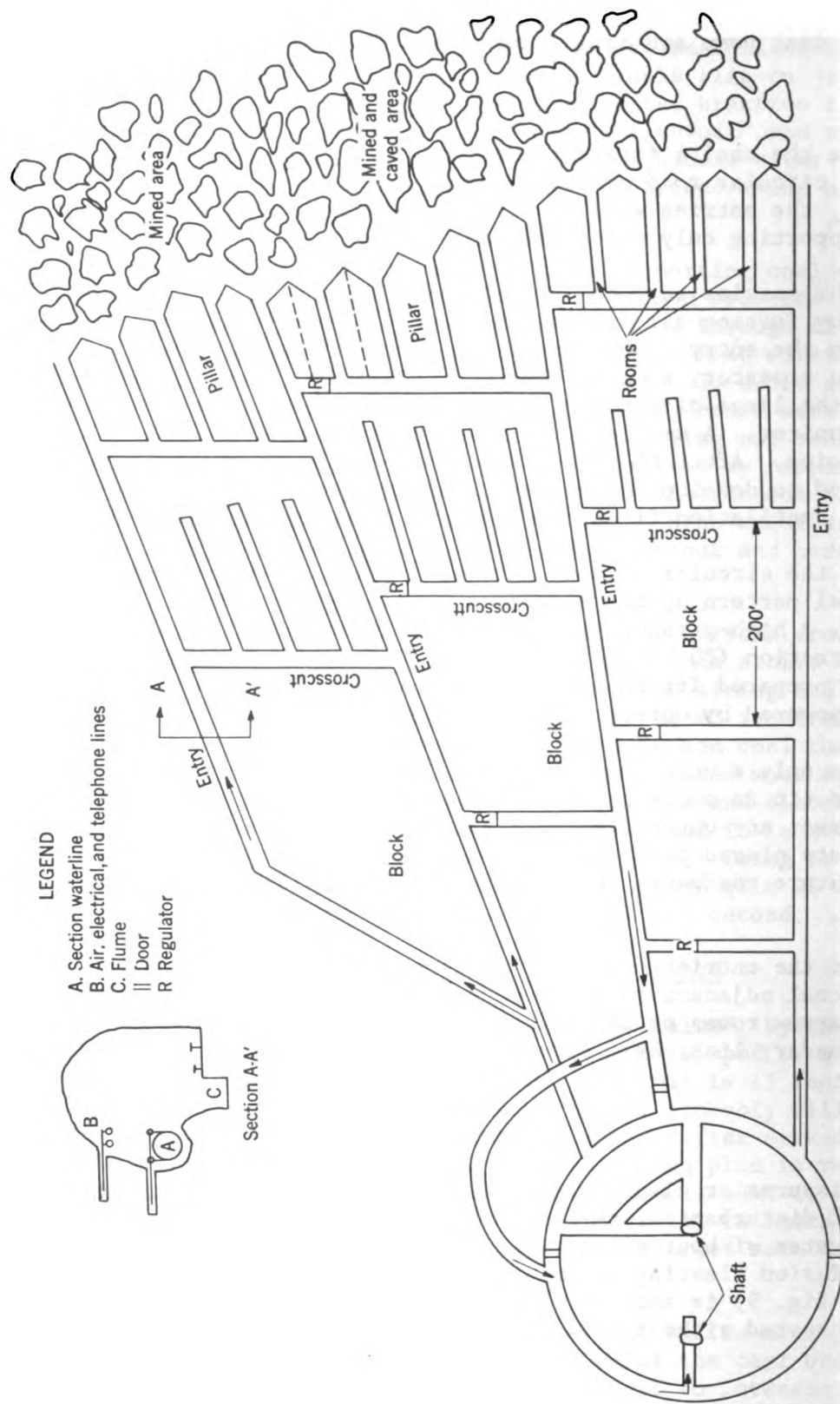


FIGURE 8. - Mining and Ventilation Method Proposed for Dipping Coal Beds in New Zealand.

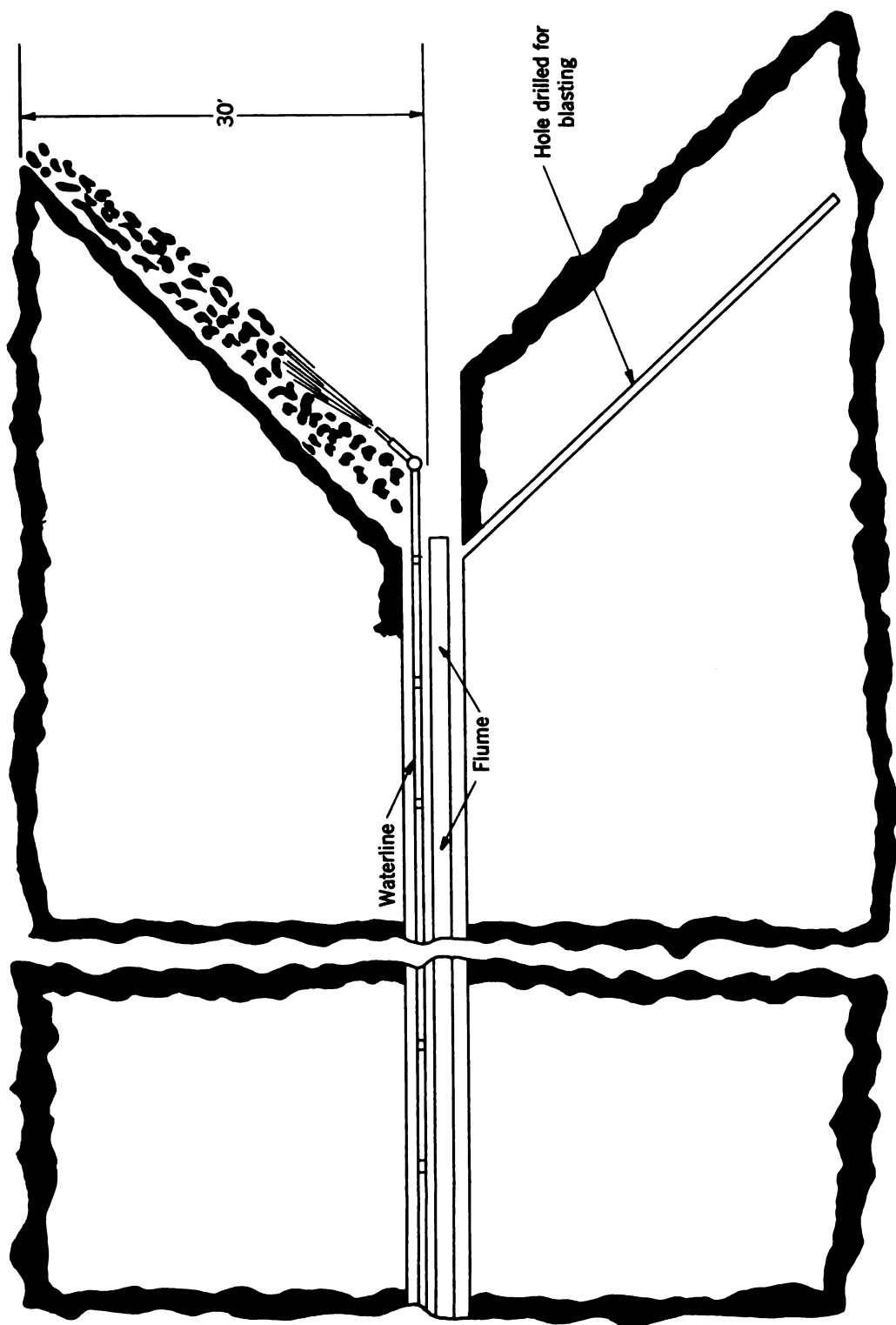


FIGURE 9. - Coal-Pillar Extraction Method Using Long-Hole-Pulsed-Infusion Blasting.

Based upon the experience in hydraulically extracting coal pillars from abandoned mines, it is estimated that 74 workmen will be required to achieve the planned production of 1,000 tons daily. The workload will be distributed as follows:

<u>Type of operation</u>	<u>Number of workers</u>
Recovering coal pillars.....	40
Developing rooms.....	8
Developing entries.....	8
Building stopping, laying pipelines, handling supplies, etc.....	14
Operating pumps.....	<u>4</u>
Total.....	<u>74</u>

The use of modern equipment may permit reducing the workforce. To simplify and standardize the operation, water-powered rotary drills, water-powered auxiliary fans, lightweight acid-resistant alloy pipes fitted with valves, and quick coupling devices will be used. Since manual labor will be required to move the equipment to a central distribution point for redistribution to the production panels, no more than two workers will be needed to carry any one piece of equipment.

Ventilation

To augment the positive ventilation supplied by the water-powered auxiliary fans, an exhaust surface fan will be installed to ventilate the retreating coal-pillar areas. This surface fan will course the air through the active working area and return it over the caved area to remove any accumulated mine gases using the circular roadway as both the intake and return air course. The ventilation method is simple and can be adjusted by a minimum of overcasts and rearranging a few stoppings and regulators.

Transportation

The coal-water mixture will be sluiced in flumes from the working places toward the central sump near the intake air shaft. Near the sump all gathering flumes will discharge into a main flume that will be elevated slightly as it approaches the sump so that it will discharge into 2 receiving bins, each having a capacity of 60 cubic feet. These bins will be an integral part of the double lock-hopper feeder and will be placed above and connected to the pressure vessels by flap valves. These valves will open and close automatically at regular time intervals. Upon entering the receiving bin, the coal will be discharged into the high-pressure transport pipeline by the following sequence of operations:

The flap valve on one of the receiving bins will open, discharging the coal into the pressure vessel. The water displaced from the pressure vessel will flow up through the receiving bin and be removed by pipelines connected to the bin, as shown in figure 10.

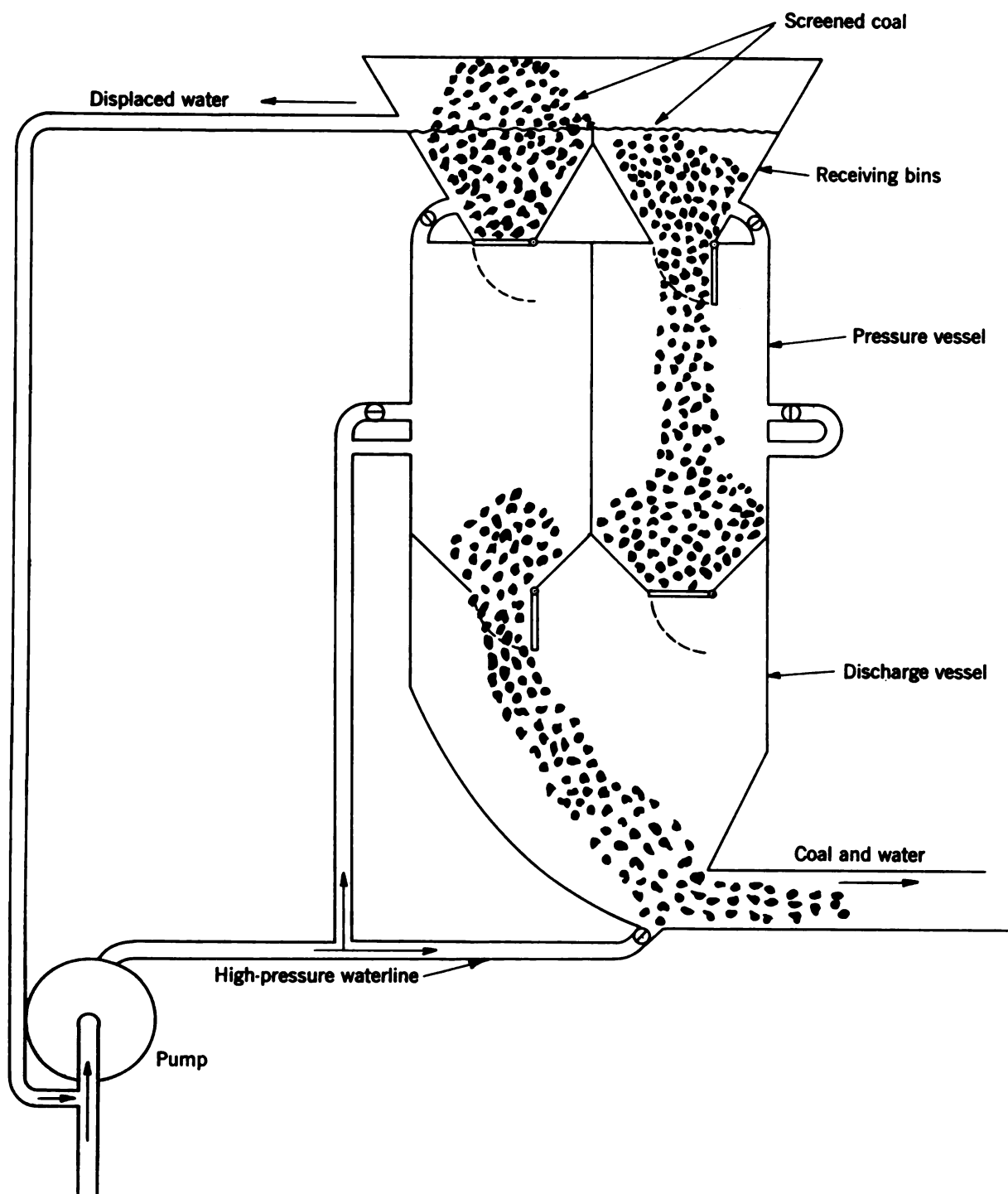


FIGURE 10. - Diagram of Double-Lock Hopper Feeder.

After 30 seconds the upper flap valve will close by means of a hydraulic cylinder. As both the pressure vessel and the receiving bin will be filled with coal at this time, it will be necessary for the valve when closing to cut through the coal. Therefore, to enable the valve to crush any coal lumps caught between it and the valve body, the cylinder will be constructed so that it will exert a force of 1 ton on the valve.

After the upper valve is closed, a valve connecting the high-pressure waterline and the pressure vessel will open, discharging high-pressure water into the vessel, and when the water pressure inside the vessel equals the pressure in the transport pipeline, the lower valve will open, discharging the coal by gravity through the bottom of the feeder and into the high-pressure pipeline. After 30 seconds the lower valve will close by means of a hydraulic cylinder, and the cycle of operations will be repeated for the other receiving bin.

The rate of discharge of coal into the pipeline will control the coal-to-water ratio, and all calculations will have been based upon a uniform discharge of 1 ton each 30 seconds. This rate results in a solids concentration of 12 percent by volume during the pumping period. However, it is highly unlikely that the discharge rate will remain constant but with only one bin discharging at any given time, the ratio of coal to water could safely rise momentarily without increasing the average concentration. The amount of coal entering the high-pressure waterline will be controlled by adjusting the time intervals for valve opening and closing, and it is believed that the discharge could be controlled to a degree by opening the lower valve only partially. With hydraulic hoisting this latter control plan may be difficult. Also, the smaller opening would be more prone to block with coal particles.

Feeder Components

The main valves will be constructed from two similar iron castings bolted together around the centerline. This construction is believed necessary to machine the recesses for the sealing strips. To reduce corrosion and wear the valve slides will be constructed from stainless steel.

The hydraulic cylinders will be operated by clean water taken to the cylinder through a control valve. This will enable the double-acting cylinders to open and close the valves. All parts subject to wear and corrosion will be constructed from gun metal, brass, or stainless steel. The piston will be made of gun metal and fitted with cup washers to eliminate leakage, whereas the cylinder will be made of brass and the piston rod of stainless steel. To prevent shock during closing, baffles will be installed over the outlet ports so that, as the piston approaches the end of its travel, the waterflow will be reduced, thereby slowing the piston speed.

OTHER COUNTRIES INVESTIGATING MINING AND TRANSPORTING COAL BY HYDRAULIC METHODS

Recent trade publications indicate that Poland has conducted field investigations to determine the economic possibilities of extracting and transporting coal hydraulically. The first field investigation is reported to have

been conducted in an open-pit mine where two men were able to extract 80 metric tons (88 short tons) per hour using a water pressure of 3,270 p.s.i.

West Germany is reported to have been investigating the extraction of coal hydraulically for about 1-1/2 years. Experimentation is now being conducted on a 320-foot longwall face in a 60° sloping coal bed having a thickness of 3.8 feet. Water is supplied to the monitor under a pressure of 2,940 p.s.i. by a three-stage reciprocating pump that has a capacity of 74 gallons per minute. The monitor may be equipped with either one nozzle having a diameter of 0.21 inch or two nozzles having 0.14-inch diameters. Water requirements range between 1.8 and 42.3 cubic feet per minute per ton of coal mined, although it is hoped to reduce this demand to 1 cubic foot per minute per ton of coal mined.

From experience, it appears that the best cutting results can be obtained with this combination of equipment and water pressure when the distance between the coal face and nozzle does not exceed 20 inches. Six men are employed in the hydraulic section, two operate the handheld monitor, and four are assigned to roof control.

Czechoslovakia is reported to be conducting hydraulic mining in a 10° to 12° sloping coal bed having a thickness of 1.3 to 2.1 feet. The coal, according to Prof. M. M. Protodyakonov's hardness scale, has a hardness of 1.2. Water under a pressure of 588 p.s.i. is supplied to a monitor equipped with a nozzle having a 1.09-inch diameter. The water requirement is 176.5 cubic feet per ton of coal mined. According to the investigators, the best cutting results are obtained when the distance between the face and the hydraulic monitor does not exceed 19.2 to 25.6 feet. Production per worker, including all face laborers, is 10 tons per man which is nearly 2-1/2 times the output realized from conventional mining in the same area.

In Great Britain the Hydraulic Transport Section of the National Coal Board is planning to conduct a hydraulic-mining investigation in the latter part of 1959. This investigation will comprise both entry development and pillar-extraction studies in a coal bed having a thickness of 5.75 feet and under approximately 250 feet of overburden. According to communications received from this section, one hydraulic monitor that will operate under a water pressure of 1,200 p.s.i. will be used.

According to foreign publications, several countries (including Great Britain, France, West Germany, Poland, and Japan) have been investigating the economic possibilities of underground hydraulic transportation of coal. Both theoretical and field studies have been made to determine the most appropriate pipe diameter with varying particle size along with water velocity and capacity. Most investigators agree that the maximum particle size should not exceed approximately one-third the pipe diameter. Also, it appears that the indirect method of feeding the broken coal into either a vertical or horizontal pipeline has more potential than using solid-handling coal pumps.

After examining the technical publications from Russia and New Zealand reviewing articles about the successful domestic application of hydraulic

mining in a gilsonite bed, it appears that conditions in many bituminous coal deposits in the United States are favorable for economical extraction, using high-pressure water jets. The Federal Bureau of Mines plans to conduct a field investigation to determine the most appropriate natural conditions and water pressures and the equipment necessary to successfully operate in United States coal beds with variable thickness, dip, and hardness.

All reported Russian or New Zealand hydraulic mining experiences concern developments in either steeply pitching or thick sloping coal beds that afford natural conditions favorable for coal transportation, but as the majority of coal beds in the United States do not have these favorable characteristics, it is planned to conduct this investigation in a relatively flat coal bed.

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